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GROUND STRENGTHENING METHOD BY MULTISTAGE LOCAL CONSOLIDATION

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Authors are investigating a ground strengthening method, which effectively consolidates the construction area of requisite minimum in a short time by local consolidation for the soft ground. In this paper, Authors research that the effect of increasing the strength of soft ground by using the three-dimensional elasto-plastic finite element analysis when the area of local loading is gradually changed. First, it was found that the strength of the soft ground just below the local loading surface increased with a short time by the local consolidation and ultimate bearing capacity increases to 2.6 times as much as the initial bearing capacity by the multistage loading. Next, analysis was carried out in the case of the multistage loading with cyclic loading. In the reloading process, loading area is reduced to 1/3 and 1/6 of the loading area of the previous stage. In this case, the ultimate bearing capacity increases to 8.25 times as much as the initial bearing capacity. In conclusion, it was found that the strength of the soft ground just under the loading surface is considerably increased by multistage local loading with reducing the loading area.

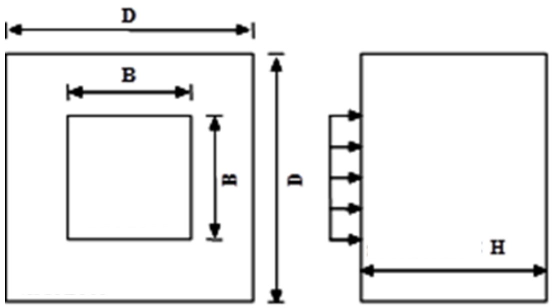
Keywords: Improvement, Soft ground, 3-D elasto-plastic analysis, Bearing capacity.

1 INTRODUCTION

This research is to find an effective ground improvement method that is not a conventional method of consolidating and strengthening the whole area for the problematic soft ground but local consolidation can effectively consolidate the exact size necessary to construction in a short time. In this paper, Authors research that the strengthening effect of the soft ground by using three-dimensional elasto-plastic finite element analysis when the area of the local loading is gradually changed in multistage local consolidation. There are few documents that directly relate to this research.

2 PRELIMINARY ANALYSIS BY FINITE ELEMENT METHOD

As a preliminary analysis, in order to study the effectiveness of consolidation strengthening by local loading, governing equations based on Biot consolidation theory were formulated and three-dimensional linear consolidation analysis by finite element method was performed. Figure1 shows the analytical model and analytical constants of the ground subjected to local loading. For the boundary conditions related to displacement, the free end of the upper end face of the analysis region, the lower end face is fixed only in the vertical direction and the side face is fixed only in the horizontal direction. Boundary conditions related to permeability were drainage on the upper and lower surfaces, and undrained on the side. The length of one side of the analytical area/



(Analytical Constant)
Lame's constant $\lambda = 1.0$, $\mu = 1.0$
Coefficient of consolidation Cv = 3.0

(Load)
Uniform distribution load p = 1.0

Figure 1. 3-D linear consolidation analytical model and analytical constants.

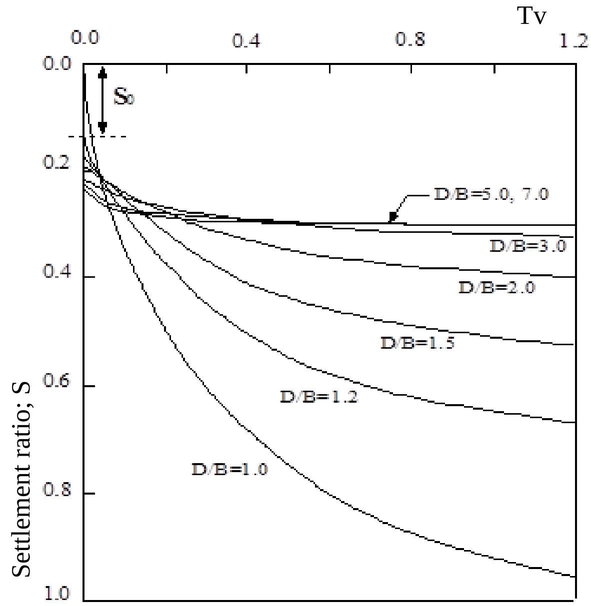


Figure 2. Relationship between settlement ratio and Tv.

length of one side of the loading area was set as D / B and this value was varied from 1.0 to 7.0 with depth of H, and the relationship between consolidation settlement and time was examined from the analytical result in each case. Figure 2 [1] shows the relationship between the settlement ratio S (settlement / settlement at U = 100% in one-dimensional consolidation) and the time coefficient Tv with respect to each of D / B = 1.0 to 7.0 (H / B = 3.75). As shown this figure, the settlement ratio decreases with increasing D / B and the settlement ratio converges to almost 0.3 when the D / B becomes 5 or more. Furthermore, in case of local loading, the consolidation subsidence progresses much faster than in case of one-dimensional consolidation, and the absolute value of consolidated settlement is also considerably small (for example, about 10% when D / B is 5.0 or more). This result gives favorable conditions that the main part of consolidation subsidence almost finishes during the construction period, the absolute value of the settlement is also small and the strength of the soft ground just under the local loading surface increases in a short period. As a second preliminary analysis, consolidation strengthening by multistage loading using the above-mentioned local loading (increase rate of C was set to $\Delta C = 0.3\ \Delta\bar{\sigma}_v$ [2], C; cohesion, $\bar{\sigma}_v$; vertical effective stress) is examined. Multistage loading is to gradually perform the next loading after being strengthened by the initial loading. With regard to the effectiveness of multistage loading, multistage loading was carried out with initial linear inner increment (the settlement is controlled within the linear range in one stage loading) and 90% increment (the loading is controlled up to 90% of the ultimate bearing stress of the previous stage) respectively using elasto-plastic incremental analysis by finite element method, and the strengthening effect was investigated. Under the plane strain condition, Figure 3 [3] shows the relationship between the load and the settlement / base width (Se / B) in case of the initial linear inner increment and the case of 90% increment. On both the initial linear inner increment and the 90% increment, the ultimate yield strength was increased, reaching 2.4 times and 2.6 times the initial ultimate bearing stress (qu = 5.14 C). From the results of this analysis, it was found that the strength of the soft ground just under the local loading surface increases, therefore it is possible to increase the ground strength without destroying the ground with multistage loading.

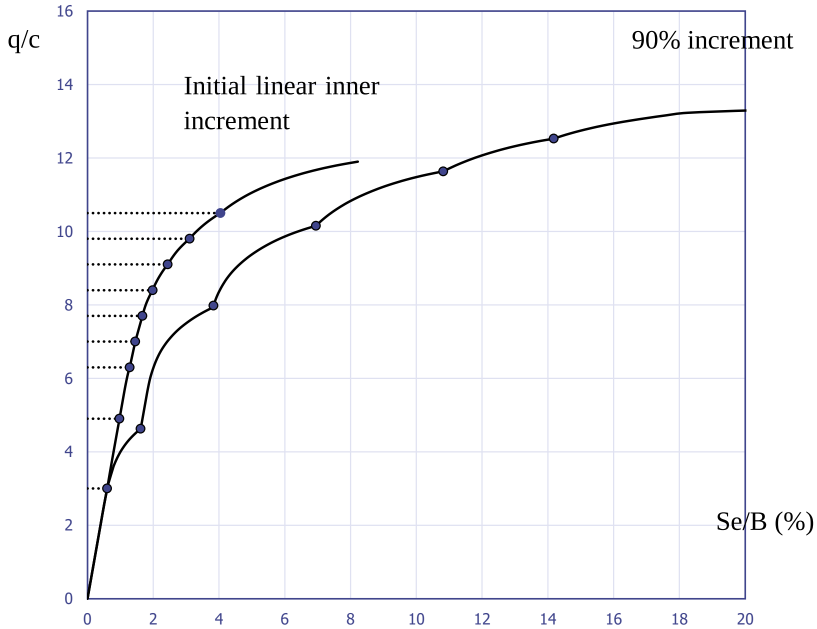


Figure 3. Relationship between the bearing capacity and settlement ratio in case of initial linear inner increment and 90% increment.

3 CONSIDERATION OF MULTISTAGE LOADING WITH CHANGE OF LOADING AREA

In this section, after carrying out the multistage loading as described above, authors examined the case of unloading once and reloading to the reducing area. Figure 4 shows this series of flows. The elasto-plastic increment analysis was also performed for this analysis. After multistage loading on the ground model, it was unloaded and reloaded to the loading area, which was reduced to 1/3 (or 1/6) of the loading area of the previous stage. Figure 5 shows the relationship between the load and the settlement / the foundation width in case where the loading area of the sixth stage is reduced to 1/3 (or 1/6) of the previous stage in the 90% increment. It can be seen that when the loading area is smaller than that of the previous stage, the ultimate bearing capacity greatly increases, and in case of the 1/6 loading area, it is 8.25 times as compared with the initial bearing capacity (qu = 5.14 C). This is because loading is applied to the central part of the loading area, which is sufficiently consolidated and strengthened by multistage loading with reducing of loading area. This shows the effectiveness of local consolidation strengthening by multistage loading that reduces the loading area in stages, giving efficient consolidation strengthening of the necessary area. As a construction example assumed at an actual construction site as shown Figure 6, it is conceivable to construct a 1/3 or 1/6 strip foundation on the soft ground which is consolidated and strengthened by multistage loading, further consolidation strengthening by building load is carried out and the bearing capacity can be greatly increased.

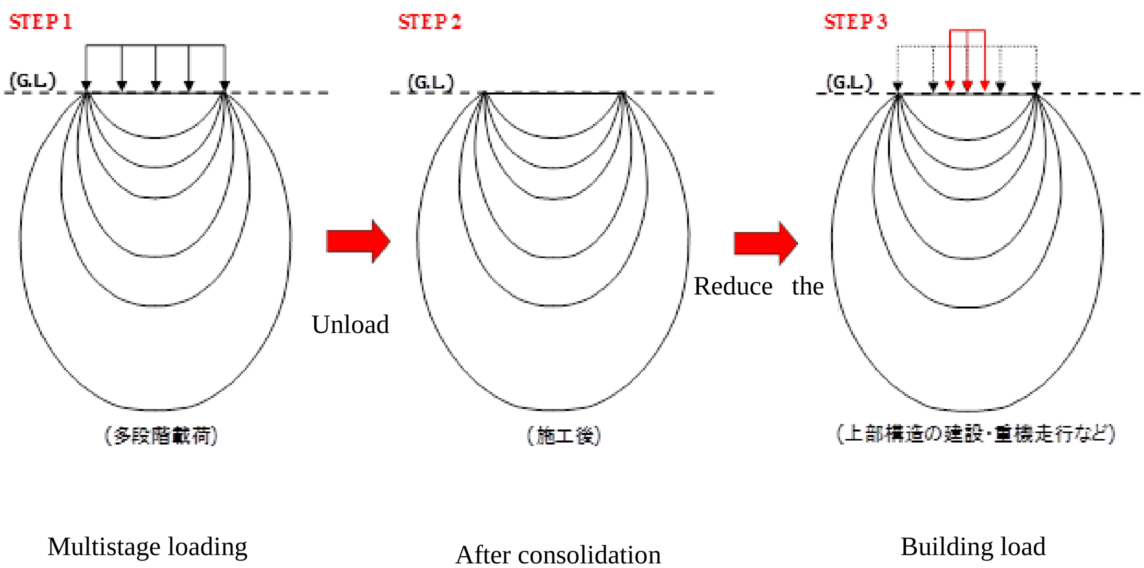


Figure 4. Construction image.

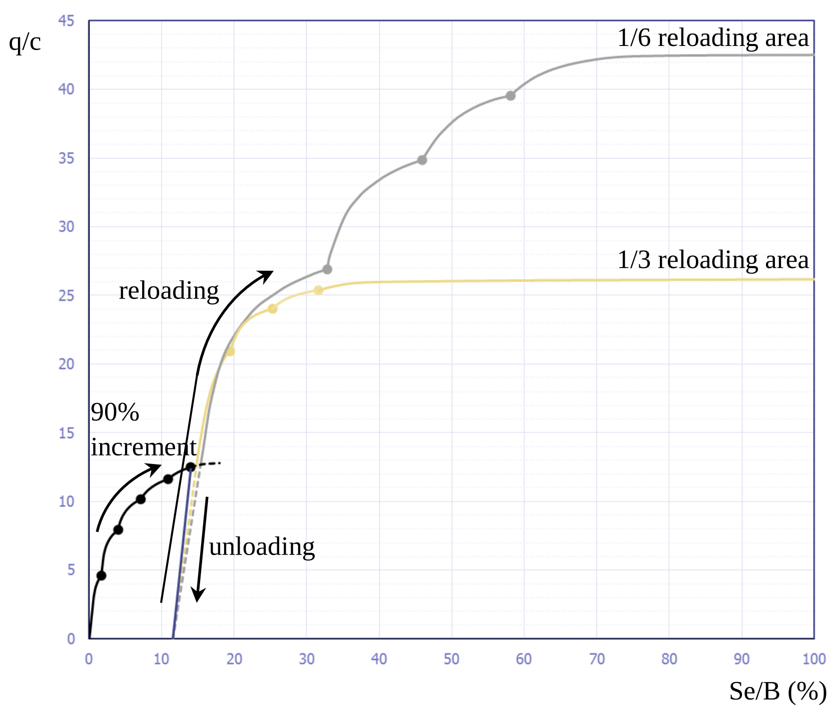


Figure 5. Load ~ Se/B relationship (90% increment, unloading and reloading to reducing area).

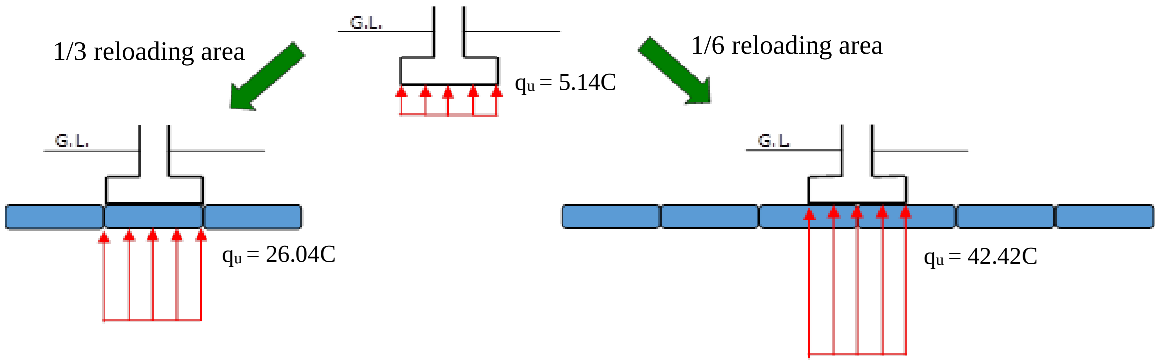


Figure 6. Improvement soft ground under the strip foundation.

4 CONCLUSION

In this study, authors investigated the effect of the increase in strength of soft ground when multistage loading on soft ground, unloading and reloading to the reduced area by three - dimensional elasto -plastic analysis. As a result, it was found that the strength of the soft ground immediately increased considerably under the loading surface. It was also found that effective and economical improved method can be developed by applying consolidation strengthening method of soft ground with suitable multistage loading and controlled loading area. As a future construction method, the building load aims to realize multistage loading by playing the role of reloading after the ground improvement by the preload method. When reloading, that area is required to be smaller than the preload area. In the future study, authors should conduct laboratory experiments on the contents of this research and it is necessary to compare the experimental results with the analytical results.

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